

## PHOSPHORUS NECROSIS OF THE JAW: A PRESENT-DAY STUDY

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### WITH CLINICAL AND BIOCHEMICAL STUDIES

BY

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A historical note on the aetiology of phossy jaw shows that present-day knowledge is little greater than it was a century ago. The varied clinical course of the disease is described together with a report of 10 classical cases not previously reported. Six cases, not amounting to true necrosis but in which healing after dental extraction was delayed, are described, and mention is made of the noticeable differences in the oral state and appearances of tartar of healthy workmen exposed to phosphorus compared with healthy workmen not exposed. But no systematic differences of any kind were found in the incidence of general infections, fractures of bones, haematological findings, and biochemical studies of blood and urine in two groups of healthy men most exposed and least exposed to phosphorus in the same factory. An intensive study in hospital of a case of classical necrosis showed no departure from normal, except delayed healing following bone biopsy from the iliac crest, and a reversed polymorphonuclear/lymphocyte ratio.

In the discussion the time of onset of necrosis after first exposure to phosphorus, clinical and radiological diagnosis, the organisms present, personal susceptibility, the appearance of the sequestra, and regeneration of bone are considered. An up-to-date note on prevention of the disease is given, although this has met with only partial success. Some persons are highly susceptible and, whilst complete protection is impossible in the light of our present knowledge, early diagnosis and modern treatment have robbed the disease of its terrible manifestations of Victorian times and turned it into a minor, although often uncomfortable complaint, with little or no resulting disability.

Phossy jaw, or phosphorus necrosis of the jaw, has been described as the most terrible of the industrial diseases, and, indeed, its fearsome appearance in Victorian times with a reported 20% mortality in Europe was the sharpest spur to international industrial legislation. It has often been said that the Berne Convention, forbidding the use of white (yellow) phosphorus in the match industry, which Great Britain ratified in 1906, is the supreme example of how legislation can wipe out an industrial disease. But a little reflection will question the truth of this, for other industrial diseases cannot similarly be legislated out of existence and in fact phossy

jaw has not been eliminated. The Berne Convention simply precluded the major application of white phosphorus for making matches. Today only about 1% of the white phosphorus made and converted into its non-toxic red allotrope goes to the industry although the overall weight of phosphorus for this use is about the same. It follows that the manufacturers of phosphorus have a theoretical exposure of about 100 times that of 60 years ago. Whilst it is almost an aphorism that the user of a toxic product is more likely to experience injury than the manufacturer, it would indeed be a surprising finding that phossy jaw no longer existed even though almost all of the phosphorus is processed into safe forms before leaving the manufacturer's premises.

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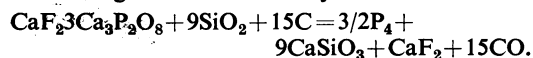
It is part of the object of this paper to examine the reasons why phossy jaw has changed its character from the fulminating spreading condition of the nineteenth century, to its present very mild form. It is no doubt largely due to the vastly improved conditions of our time, which have sent the old type of phossy jaw into the limbo of pathological curiosities such as cancrum oris, fungating tumours, eroding aneurisms, and Pott's disease of the spine.

### Sources and Manufacture of Phosphorus

Elemental phosphorus does not exist in nature, but phosphates are lavishly distributed throughout the animal and vegetable worlds; for example an 11-stone man would yield about 1.5 lb. (0.7 kg.) of elemental phosphorus. The element was first isolated from human urine by Brandt, a physician of Hamburg, in 1669. Hunter (1957) reports that Brandt's better educated, but less successful, colleagues described him as "an uncouth physician who knew not a word of Latin". In England the process was rediscovered by Boyle in 1680 when he evaporated urine to dryness and distilled the residue with sand, unknowingly copying Brandt.

Phosphorus was first manufactured commercially from the reduction of animal bones. It is now manufactured from phosphate rock obtained from naturally occurring deposits in many parts of the world, particularly Florida and Tennessee, North Africa, and some Pacific islands. The rock exists as calcium phosphate,  $\text{Ca}_3(\text{PO}_4)_2$ , fluorapatite,  $3\text{Ca}_3(\text{PO}_4)_2 \cdot \text{CaF}_2$ ; chlorapatite,  $3\text{Ca}_3(\text{PO}_4)_2 \cdot \text{CaCl}_2$ , and hydroxyapatite  $3\text{Ca}_3(\text{PO}_4)_2 \cdot \text{Ca}(\text{OH})_2$ . Fluorine is usually present, as are iron and aluminium; and some other elements, including arsenic, are also present in small quantities.

Phosphate rock, silica chippings, and coke or anthracite are heated to about  $1500^\circ\text{C}$ . by passing an electric current through the mix using carbon electrodes in a carbon-lined furnace. Carbon monoxide and phosphorus vapour come off the top of the furnace and a molten slag consisting of a heavier ferro-phosphorus and lighter calcium silicate, is run off the bottom. The calcium silicate when cooled is dug out for use as road metal; it is occasionally radioactive. The phosphorus vapour undergoes a series of processes which free it from dirt carried over from the furnace burden and is collected under water. The general reaction may be written as:



The bulk of white phosphorus made is converted into phosphoric acid by reacting it with air and

hydrating the resultant  $\text{P}_4\text{O}_{10}$  with water under carefully controlled conditions. Arsenic is then removed. An alternative method of making phosphoric acid is by the "wet acid" process, where the phosphate rock is reacted with sulphuric acid. Since arsenic and fluorine are not removed phosphoric acid made in this way cannot be used in foodstuffs without further purification. From the point of view of phossy jaw, or any other manifestation of phosphorus poisoning, the wet acid process is completely safe; it is the very reactive white phosphorus which is dangerous to man. Phosphoric acid is made by both processes in this country.

Whilst sporadic cases of phossy jaw have been reported in a variety of industries using white phosphorus in, for example, a phosphor-bronze worker and a maker of rat poison, the vast majority of cases formerly occurred in the match industry when white phosphorus was used. Fortunately, when the English match industry was still in its youth a safe form of phosphorus was discovered by Professor Schrötter of Vienna. Schrötter found that prolonged heating of yellow phosphorus in the absence of air converted it into amorphous, or red, phosphorus which proved to be biologically harmless. Arthur Albright, who pioneered phosphorus making in this country, had already decided to give up making white phosphorus when he heard of Schrötter's work. Albright visited him in 1849 and bought the patent. Schrötter's difficulty was that he could not make amorphous phosphorus without explosions. Albright solved this problem although Threlfall (1951) reports that he brought the local constabulary into his factory at Oldbury on several occasions to investigate fires and explosions occurring during the course of his experiments. Albright showed his amorphous phosphorus at the Great Exhibition of 1851. The Lundström brothers of Sweden took samples and made up matches which lay forgotten for three years. They later remembered them and to their astonishment they still lit. They were shown at the Paris Exhibition of 1855, and this became the foundation of the Swedish match industry.

In this country the use of amorphous phosphorus was pioneered by Bryant and May in their "Safety" matches. Amorphous phosphorus is put on the box and the match head consists of potassium chlorate and other substances. The second biologically safe match came later when white phosphorus was directly reacted with sulphur to form phosphorus sesquisulphide,  $\text{P}_4\text{S}_3$ , which, with other ingredients, is put on the head of the match. The striking surface on the box is sandpaper.

With the invention of not only safer, but more suitable forms of phosphorus, many countries

considered the abolition of white phosphorus for making matches. To Finland goes the honour of first abolishing white phosphorus in 1872, followed by Denmark in 1874, and Switzerland in 1898. In 1906 all the major countries of Europe ratified the Berne Convention which forbade the manufacture or import of white phosphorus for making matches.

### Aetiology of Phossy Jaw

The cause of phosphorus necrosis of the jaw is unknown but it is probably due to phosphorus or its lower oxides. The first recorded cases of phossy jaw came from Vienna in 1839 from the rapidly expanding European friction match industry, but these reports were closely followed by others from different countries. Originally made from antimony sulphide, potassium chlorate, and gum arabic and invented in 1862 by John Walker, a chemist from Stockton-on-Tees, matches later came to be manufactured from phosphorus because they ignited more easily. Robert Boyle had, however, invented the first friction match 150 years previously. This match was a sulphur-tipped wooden splint which was drawn across paper coated with phosphorus. The old antimony match was called "a lucifer" and the new phosphorus matches were called "congreves" after Sir William Congreve (Hunter, 1957). Despite this the older and more descriptive term lucifer returned to become immortalized in the song "Pack up Your Troubles in Your Old Kit Bag" nearly a century later.

In common with the beginnings of the industrial revolution in England, match making on the Continent was largely an industry carried on in the cottage homes of the workpeople, and only gradually were factories built, the first being opened in Vienna in 1832. In England, John Simon, the Medical Officer of the Privy Council, discussed in his Fifth Report of 1862, "Occupations which have to do with Phosphorus". He wrote:

"The utilisation of phosphorus in various popular contrivances for producing instantaneous light has, for the last 30 years, been a special industry. And with the growth of this industry a new disease has come into existence. About 18 years ago observations began to be published to the effect that, of the workpeople who in the new industry were exposed to the vapours of phosphorus, some, but apparently not a large proportion, suffered in consequence of the exposure a peculiar disease of the jaw-bones; namely—that, after a variable premonitory period of such moderate local irritation as might be supposed to be mere common toothache or gumboil, evidences of destructive bone-disease—affecting commonly at first only a small portion of bone, but perhaps eventually invading all or nearly all of the lower

or of the upper jaw, would become manifest—that in average cases of this very painful and very loathsome disease, recovery was not got except after suffering which could scarcely be of less than many months', and often were of some years', duration—that in severe cases the patient was likely to sink under the pain and exhaustive discharges of the disease, and that at best he would be left deformed and mutilated. Almost as soon as the disease was recognized, investigations were made into the details of its pathology. And these investigations established as certain, that the disease is in its origin purely local—that it depends on an influence which the fumes of phosphoric acid, when they get dissolved in the saliva, are able to exert directly and specially within the mouth.

"From the inquiry which has now been made under their Lordships' direction into the circumstances of the phosphorus industry in England, it appears (as had been anticipated) that the jaw-disease which I have described is not of frequent occurrence. Dr. Bristowe, after visiting all the known match-making establishments in England—57 establishments, employing about 2,500 hands, has not been authentically informed of more than 59 cases (past or present) of jaw-disease. And though doubtless in some instances information has been withheld from him by manufacturers who feel that their experience has not been creditable to them—so that the total production of jaw-disease during the last 30 years has been greater, perhaps considerably greater, than these numbers express—yet very probably there would be no understatement of the truth in applying these numbers to the *present time*, and in assuming that now (with the improved arrangements which a less favourable early experience has induced all respectable manufacturers to adopt) not more than two or three cases of the jaw-disease are annually produced in England."

In the same report Dr. Bristowe writes:

"... it would appear that the first to call attention to the disease occurring in lucifer-match manufactories was Dr. F. W. Lorinser, of Vienna; who published, in the year 1845, an account of 22 cases of jaw-disease, of which the earliest had occurred as far back as 1839. . . . The first recorded case of jaw-disease, occurring in English practice, is described in the 'Medical Times and Gazette' for December 19th, 1846, as having been under care in University College Hospital, and is again briefly alluded to, in the Guy's Hospital Reports for 1846-7. Shortly afterwards, cases of the same disease were reported by Taylor of Nottingham, Stanley of St. Bartholomew's, and Simon of St. Thomas's. Subsequently, numerous isolated cases and records of the disease have appeared in various journals, English and foreign. The prevalence of the disease in France is well shown in Chevallier and Poirer's report (Journal de Chemie Medicale, March 1858, p. 139), in which it is stated, that out of 60 persons known to have been attacked in France, more than half had died. Its frequency in Prussia is evidenced by the report of 'A scientific deputation for medical affairs in Berlin' (Vrthjhr. Schr. f. Grchtl. Med. Band. xiii, p. 258),

from which it appears that in 75 Prussian manufactories from 35 to 45 cases of jaw-disease had come under notice. Its occurrence in the manufactories of New York is pointed out in the 'Medical Times and Gazette' for 1859, vol. 1, p. 400; and its ravages in Zurich are proved by the remarks of Dr. Bilroth of that city (reported at page 610 of the first volume of the same journal, for the year 1861), who asserts that there had been for some years past an average of four or five cases per annum, and that during the year in which his remarks were published 11 had occurred. . . .

"The only disease, in fact, which prolonged experience has shown to be indigenous in congreve-match manufactories, is that which, from its exceptional character, first drew medical attention to them, viz., necrosis of the maxillary bones. It was observed that, amongst those who were employed in the making of matches, and especially among those of them who were most exposed to fumes arising from the composition employed, some, sooner or later, became attacked with the disease in question; and it was soon established that the proclivity to this disease, though varying in intensity in different manufactories, was a special evil common to them all. . . .

"As regards the relative frequency with which the jaws were affected, it was observed, that, on the whole, the lower jaw was more frequently the seat of disease than the upper; and this difference (notwithstanding that it was so little, in the cases collected by Von Bibra and Geist, that out of 68 there were 21 in which the superior maxilla alone was affected, and only 25 in which the lower maxilla alone was involved) seems to have been noted by almost all observers. Occasionally both jaws were affected, either simultaneously or successively.

"A pathological difference was observed in the progress of the disease in the two jaws. Thus, in the case of the upper jaw, it was, I believe, invariably noted that the sequestrum was bare, and that no new bone was developed around it; that the process of necrosis was unattended by any, the slightest, attempt at repair. In the case of the lower jaw, on the other hand, it was with equal invariability observed that, after the removal of the bone, a framework of new bone was left behind—small and imperfect, it is true, but still replacing, and to a certain extent fulfilling the functions of, the original organ; and it was further observed, that the dead jaw itself was clothed, especially below, with an imperfect layer of slightly adherent new bone. This latter appearance was considered, by Dr. Geist, to indicate, that the disease was essentially, and in the first instance, periostitis; and that the disease and death of the bone were merely a secondary occurrence—a view which has, I believe, been generally accepted. . . .

"Professor Martius, of Erlangen, and Dupasquier, of Lyons, having observed that arsenic was contained in the phosphorus employed in certain manufactories, assumed that this was the deleterious agent. But this explanation, also, admitted of easy refutation; for, as Geist pointed out, not only was this disease unknown among arsenic smelters, but it occurred, and has continued to occur, in factories in which the phosphorus used contained no arsenical impregnation whatever. The *prima facie* explanation, however, and that which became generally

accepted, is, that the disease was due to the inhalation of the fumes of phosphorus. The proofs of this were manifold; 1st, phosphorus was the only article, universally employed in match-making, which gave off vapours, the effects of which had hitherto not been tested by experience; 2nd, those persons, who were most exposed to these vapours, were just those who were found to be those most liable to disease; and, 3rd, it was in those factories, in which the composition employed was richest in phosphorus, and those which were worst ventilated, that jaw-disease chiefly occurred. The experiments, moreover, of Von Bibra on rabbits confirmed the truth of this view. He exposed these animals, for periods varying from eight days to eight weeks, to the fumes of phosphorus; and showed, that under the influence of those fumes in a concentrated form, bronchitis, pneumonia, and gastric disturbance frequently supervened; and that, after lengthened exposure, an eruption of the skin, attended by falling out of the hair, manifest itself. But he observed also (which is more to the point), that after extracting some of the teeth, and partially (by accident) fracturing the jaw, so as to expose the periosteum, then, under the influence of the fumes of phosphorus, changes took place in the jaws of rabbits identical with those which had been observed in the jaws of congreve-match makers.

"Yet, although the disease was satisfactorily traced to the fumes which phosphorus emitted during the process of match-making, the precise compound, which acted deleteriously cannot be said to have been conclusively determined. Von Bibra thought the efficient agent to be hypo-phosphorous acid; but whether it was this specially, or whether it was phosphorous acid, or some other oxide, or all of them indifferently, remained a debatable question.

"But it was observed that a small proportion only of those, who were exposed to the fumes, became affected by the disease; and the question—why, of two persons equally exposed, one should suffer and the other should continue healthy—was recognized, therefore, as an important one, and became the subject of investigation. Some supposed that the scrofulous, and weak in health, were specially liable to the disease. Dr. Lorinser considered that the fumes acted by producing, in consequence of absorption, an unhealthy condition of the blood, and that the jaw-disease was simply a secondary effect, brought about, in persons thus infected, by some accidental exciting cause; and, in proof of this view, he drew attention to a peculiar, sallow, bloated complexion, and to a dull expression of eye, which the patients presented, and to the occurrence among them of gastric derangement. These views were adopted by some subsequent observers. Dr. Geist, however, combated them, and contended that the affection was purely a local one, and produced by the direct influence of the phosphorus fumes on the parts liable to disease. The evidence on this side of the question was that the patients, in the majority of cases, were to all appearance perfectly healthy until the disease manifested itself, and that many of them, even, retained the aspect of health during nearly the whole progress of the disease; that the jaws, the only bones exposed directly to the fumes, were the only bones that ever became affected; and, lastly, that the only

sufferers were those in whom one or more of the teeth were carious. Dr. Geist came, in fact, to the conclusion, that the phosphorus-fumes acted on the jaw solely through the intermediation of decayed teeth, and brought forward good arguments, and several striking cases, in confirmation of his conclusion. Roussel arrived at the same result. And almost all subsequent writers on the subject, including Mr. Simon, have accepted, or confirmed, the views of these authorities. It may be added, that Von Bibra's previously-cited experiments on rabbits (in the course of which, only those rabbits were affected with maxillary periostitis, in which the jaw-bone had been broken, and the periosteum thus exposed directly to the action of the phosphorus-vapours), afford additional evidence on the same side of the question. Dr. Billoth, of Zurich, however, who has had very extensive opportunities of observing the disease, seems to be a dissident; for he states, in some observations published early in 1861, that although the disease is not due to any form of cachexia, it is not unfrequently observed in persons with originally remarkably handsome and healthy teeth, and that, why phosphorus specially affects the jaw, is as inexplicable as why mercury affects the parotid, arsenic the stomach, and so forth."

The reason for quoting Bristowe at length on aetiology is because this is exactly the state of present-day knowledge. It is not known how the toxic substance responsible for necrosis gains access to the jaw, whether it is a local action through a breach in the integrity of the jaw coverings, or a general systemic action causing lowered resistance in all bone in which the jaw shares. It appears to be necessary to have both phosphorus (or other chemicals) and infection from micro-organisms, and the only place where the two can commonly coexist is in the jaw.

### Theories of Causation

Hunter (1957) describes the case of a patient given strychnine and phosphorus pills who was advised to give up taking them if the strychnine made him twitch. The patient reported no twitching but returned 27 years later with advanced necrosis of the jaw. This occurred in the seventeenth century and, although there does not appear to be any other case of phossy jaw caused by ingestion reported in the literature, Threlfall (1951) records that within living memory, cans for ladling water over the phosphorus in a phosphorus-making factory have been used for making tea. Probably a great deal of phosphorus has been ingested over the years by such workmen without apparently affecting their health adversely. On the other hand many workers have shown bone effects in animals fed with phosphorus. Fleming, Miller, and Swayne (1942) showed that in young animals injected or fed with

phosphorus a thickening of the epiphyseal line by new bone tissue with the extension of thin, more or less closely packed, trabeculae into the shaft occurred. This finding was not observed in any of the controls.

The most widely-held theory is that the noxious chemical enters directly into the jaw and this, together with the flora of the mouth, gives rise to infection, and a sequestrum forms. An important modification of this theory is that the chemical concerned might be concentrated in the saliva. One of us (A.W.G.), who is a dental surgeon to two completely unconnected factories in the same area (one an engineering, the other a phosphorus-making factory), has noted distinct differences in the tartar on the teeth in the two groups of workmen. Another dental surgeon (A.P.) has noted similar differences in two different phosphorus factories, in one where the exposure is slight and in the other where it is heavy.

The condition may arise following damage to the gingival margin or supporting structures of a tooth. Damage may occur as a result of direct trauma, or from inflammation, thereby opening up a breach in the overlying tissues of the bone. Examples of these are when there is gingival inflammation as a result of bad oral hygiene, a very carious tooth which may result in inflammation of the dental pulp leading on to peri-apical infection, extraction of a tooth or teeth, and where an ill-fitting denture has caused some inflammation of the overlying mucoperiosteum.

In the edentulous mouth, provided that the patient wears dentures, the lesion associated with phosphorus necrosis appears to arise in the area where the patient has complained of a "denture sore". Although the initial lesion may occur as in any other case of "denture sore" where the patient has not been exposed to phosphorus fume, in the case of the exposed patient the condition does not appear to heal spontaneously when the denture is not worn. Instead the bone in the area of ulceration tends very slowly to become denuded of mucoperiosteum until there is an area of exposed bone.

There is considerable evidence for believing that phossy jaw is part of a systemic disease. Dearden (1899) recorded two cases of fracture of the femur in phosphorus workers and noted that reports of multiple spontaneous fractures in phosphorus workers had been recorded in many countries. One of us (M.A.C.) has had experience of two cases of long-standing osteomyelitis, one of the lower end of the tibia and the other of the clavicle, breaking down after exposure to fumes on the phosphorus plant. They were both removed from phosphorus and subsequently healed normally.

Kennon and Hallam (1944) reported a case of a man who, after being exposed to phosphorus for

18 months, joined the army. Seven months later he experienced a sudden acute pain in the left side of his face and he was subsequently found to have developed phossy jaw. Hunter (1957) says that cases have occurred up to two years after leaving exposure. Both these experiences are suggestive of a systemic and not a local absorption. Similarly, with excessive exposure to radium, a necrosis may be precipitated by the mere extraction of a tooth and the condition is very similar to that which occurs after exposure to phosphorus. Again the very slow separation of the sequestrum is akin in the two cases.

The luminous-dial painters who licked their brushes developed a very severe necrosis of the jaw (Martland, 1931). Subsequent development of osteogenic sarcomata elsewhere adequately proved the wide skeletal distribution of radium. The jaw necrosis was caused by a superimposed bacterial infection on an existing generalized radiation osteitis. Cases of jaw necrosis occurred some five years after workers had left their employment and usually long before the osteogenic sarcomata elsewhere had had time to develop. As has been mentioned, phosphorus was originally obtained commercially from animal bones and therefore phossy jaw cannot itself be due to ionizing radiations. But there is considerable theoretical evidence of a systemic, as against a local, action. Many workers have reported a polymorphonuclear leucopenia (or a relative lymphocytosis) in phosphorus poisoning. This is a constant finding in radiation and chronic benzene poisoning where necrosis of the jaw may also occur. Of interest in this connexion is a differential count in our Case 3 where there were only 30% polymorphs as against 61% lymphocytes. (During a month in hospital this ratio returned towards normal, although it did not quite reach it.) Our other researches, however, have failed to demonstrate any evidence of a systemic absorption in phosphorus workers.

#### Causative Chemicals

It has been noted that arsenic was considered as a cause a century ago. There are present-day reasons for suspicion about this element. The garlic odour reported repeatedly in the literature in phossy jaw is the normal odour of arsenic, not phosphorus; the latter has a distinctive, but not garlic-like, odour when burnt in insufficient supplies of air. The clinical course of classical phossy jaw is remarkably like two other conditions, x-ray necrosis and the necrosis which appears in the bone supporting the root of a tooth which has been killed with arsenic, a not uncommon dental procedure 20 or 30 years ago. On the other hand analysis of sequestra for arsenic has so far been inconclusive. Although the disease

occurred when animal bone (with less than 10 p.p.m. arsenic) was the raw material, considerable arsenic came from the coal with which the retort was charged. Conceivably both elements are necessary to produce phossy jaw.

#### Clinical Course

The diagnosis of "classical" phossy jaw is not difficult in the established case. But great difficulties in diagnosis are experienced in the early stages of the disease and in atypical cases which are discussed later. First, for a description of the disease as it occurred in his day, Bristowe's report could hardly be bettered. He wrote:

"The disease, it was noticed, began usually with aching in one of the teeth. At first, this was probably mistaken for ordinary toothache, and would, indeed, at times intermit. Sooner or later, however, recurrence of pain necessitated the extraction of the tooth, and the pain and annoyance for a time probably ceased. The wound in the gum, however, was found not to heal; offensive matter began to ooze from it, and *ere long* a portion of the alveolus became exposed. Occasionally, the portion of bone thus denuded came away, bringing with it, perhaps, one or two of the neighbouring teeth, and the disease made no further progress. More frequently, however, the disease continued to spread; and, sometimes slowly, sometimes rapidly, more and more of the jaw-bones became denuded, the gums grew spongy and retreated from the alveoli, the teeth got loose and fell out, the fetid suppuration became more and more copious, the soft parts around grew swollen, tender, and infiltrated, and often the seat of sinuses. And thus, the disease continued to progress, till in the course of six months, a year, two years—it might be even five or six years—the patient sank from debility, or from phthisis, or from some other consequence of the local affection; or, having lost piecemeal, or in the mass, large portions—one half, or even the whole—of the upper or of the lower jaw, returned to his original state of good health, but the victim of a shocking and permanent deformity. During the earlier, and more acute, stages of the disease, constitutional disturbance, as might be expected, generally showed itself, indicated by febrile symptoms, loss of appetite, thirst, constipation, a sallow, pasty condition of the skin; and these were often associated with intense pain in the affected parts, and consequent sleeplessness. After a while, however, (especially in cases that were tending to a favourable issue), pain and constitutional symptoms diminished, and the patient sometimes recovered the aspect of health, even while necrosis of the jaw was still progressing."

Kennon and Hallam (1944) had the advantage of seeing cases at an earlier stage and they reported that a dull red spot on the mucosa may be the earliest sign of the disease. Our own clinical observations (A.P.) show that in men heavily exposed to phos-

phorus, compared with men with little or no exposure, the whole of the mucosa may be dull red, with an unhealthy, devitalized appearance, and this without any ensuing necrosis. In cases of phosphorus necrosis pain is usual, but variable in severity, and worse at night. Undoubtedly some men experience severe pain, but in others pain is minimal or absent. In Case 5 of our series the denuded alveolus was discovered on routine inspection; the man was completely unaware of it. Necrosis frequently starts in an area where there has been a history of toothache or extraction followed by delayed healing or a "denture sore".

In those "classical" cases where a sequestrum eventually forms in one or the other jaw, the onset may be very acute, with abscess formation needing drainage from the outside, fever, pain, and prostration. Other cases smoulder slowly, with the development of a tiny sinus with a little glairy pus. After the initial stage has been treated with antibiotics the subsequent development is similar in both types of case. Weeks, or more usually months, later a circumscribed sequestrum is released from a dry, or nearly dry, socket.

Such cases, with known exposure to phosphorus, cannot fail to be recognized. There are other conditions involving loss of bone which also occur in persons who have never been exposed to phosphorus but which occur much more frequently in phosphorus workers. In edentulous patients inflammation of the crest of the alveolus with fragmentary necrosis of bone is uncommon in outside clinical practice but occurs not uncommonly in phosphorus workers. The clinical condition is identical in the two cases and can only be distinguished on the occupational history. But loss of small pieces of the bone plate or "egg-shell" necroses, if not pathognomonic of phosphorus exposure, are not unusual in cases after sequestration has occurred.

#### Case Reports

**Case 1.**—A male, aged 34, was employed on chemical plant manufacturing phosphorus from May 1956. Dental condition was good, with a few small fillings.

In February 1958, patient complained of pain 65 area; he had had previous irritation in this region owing to food trapping between 65. 5 was extracted and systemic penicillin given. For the next six weeks patient had recurrent swellings, discharge, and pain which, in spite of local treatment and antibiotics, worsened. He was referred to a consultant oral surgeon at hospital. The socket was still patent after six weeks, gingivae 8-3 were swollen and inflamed, and there was oedema of the floor of the mouth and severe pain; a purulent discharge and mobility of 76 43 followed.

Antibiotics were given constantly; the radiograph suggested involvement of 43.

In a further 10 days the pain increased, and there was copious discharge of pus but little swelling at the site, gross foetor, numbness of the right mental region, and the cervical glands were very tender. The patient was given intramuscular morphia and tetracycline; the condition improved and he was operated on five days later. A large sequestrum and 6 432 were removed and the area cleaned down to sound bone. Healing took place without setback or breakdown. Sensation returned to the lip after a year.

This case is interesting as it was unusually acute in onset and course, and its origin appears to have been paradental.

**Case 2.**—A male, aged 42, had been employed at a chemical plant exposed to phosphorus from October 1929. Dental condition of patient was good though he had had much conservative treatment including a root-filled tooth 2.

In June 1947 23 area became swollen, and then there was purulent discharge via sinus; 2 was extracted. Twelve months later in June 1948 sinus with discharge 23 area, radiography showed large area of rarefaction; 3 was extracted; dressings and syringing. In July 1948 4 became very tender and was extracted, and in September 1948 6 was extracted. In October 1948 there was an area of exposed necrotic bone 6 region and patient was referred to consultant oral surgeon. Pieces of bone continued to exfoliate in spite of frequent local treatment. In March 1949 patient was operated on in hospital, when a large sequestrum was removed from upper left maxilla; this was quite free from underlying sound bone; the area healed slowly. In September 1949 further spicules exfoliated and an antro-oral fistula was suspected. Patient has since had recurrent pain in the left maxillary sinus (? sinusitis) without further sequestra or sinuses and no abnormality apart from delayed healing with subsequent extractions.

**Case 3.**—A male, born October 28, 1921, was employed in phosphorus from February 1954. He had 7 extracted in June 1954 after removal from phosphorus. There was some delay in healing but he was able to return to exposure a month later. He was seen at hospital in October 1956 complaining of soreness in the right upper jaw for one week. On examination 84 were loose and tender to percussion and an area of necrotic bone was visible anterior to 8 (Fig. 1). Sinus radiographs showed considerable mucosal thickening in the right antrum (Fig. 2). A fairly large sequestrum became defined, but was not clearly visible until mid-January 1957 (Figs. 3, 4, 6, and 7). The later intra-oral appearance is shown in Fig. 5. The sequestrum separated 15 months after the onset of the disease, with a clean cavity and no oro-antral fistula. Healing was uneventful. Subsequent sinus radiographs showed the right antrum had returned to normal. Fig. 8 shows the extracted sequestrum, which is about 2 × 1 cm. Radiographs taken four years later showed some bone regeneration of the maxilla (Fig. 20), but this was not as marked as in the mandible (see Case 6, Fig. 19). Some months later this man was admitted to hospital for investigation (see below).





FIG. 1.—Case 3: Early intra-oral appearance.

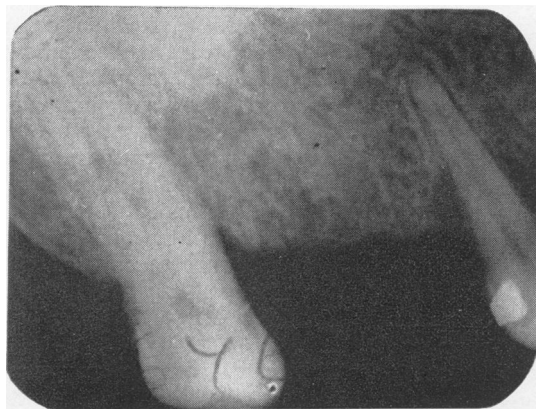


FIG. 3.—Case 3: No demarcation of sequestrum yet visible.



FIG. 2.—Case 3: Radiograph taken at same time as Fig. 1. Right antrum shows opacity.

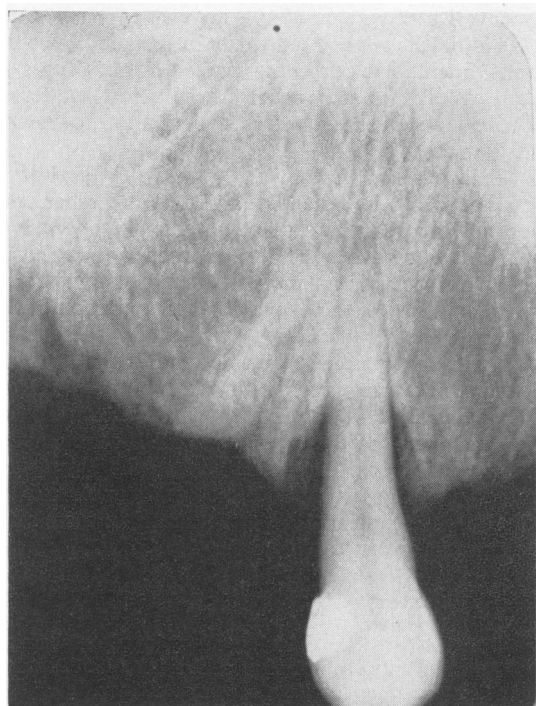


FIG. 4.—Case 3: Separation of sequestrum not yet visible.

**Case 4.**—A male, aged 56, was exposed to phosphorus from 1941. Patient was exposed for seven months and was then removed and made edentulous. On healing he returned to exposure and was inspected every three months by the works dental surgeon; no abnormality was discovered until February 1954. He was immediately removed from exposure and remained so subsequently. He was suffering irritation of upper and lower right canine

regions, and radiographs revealed pieces of root which were extracted. The areas failed to heal in spite of dressings and local treatment. In February 1955 whole-head radiographs were taken by a consultant radiologist and found to be normal. He was referred to a consultant oral surgeon in November 1955 at hospital, who noted sinuses in both areas with palpation of underlying bony fragments: radiographs now revealed rarefaction. Patient



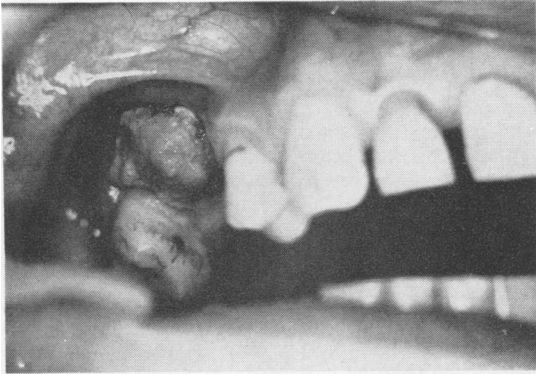


FIG. 5.—Case 3: Later intra-oral appearance.

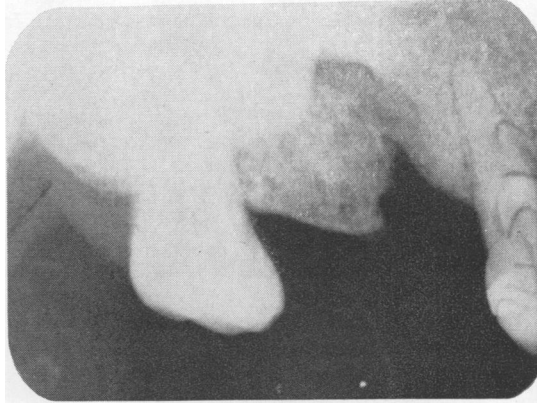


FIG. 7.—Case 3: Line of demarcation clearly shown.



FIG. 6.—Case 3: Sequestrum demarcated.

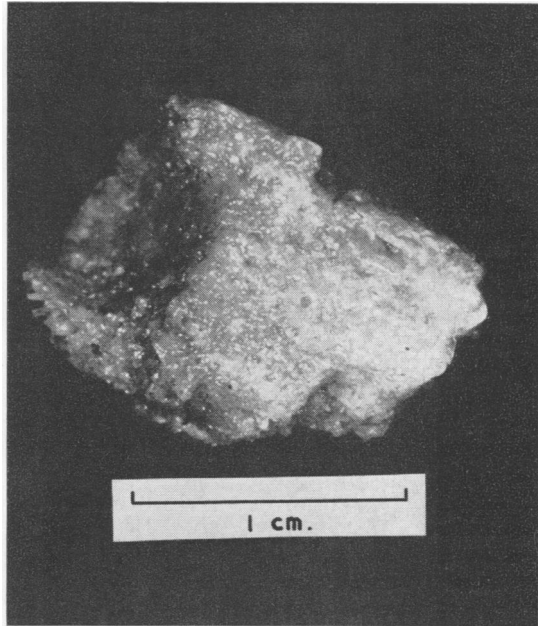


FIG. 8.—Case 3: Exfoliated sequestrum against centimetre scale.

was operated on under general anaesthesia and necrosed bone was found and removed; the underlying bone was healthy. Normal healing occurred.

**Case 5.**—A male, aged 28, worked for eight days in phosphorus in April 1952 and again for two months at the end of 1954. He was re-employed at the end of May 1956. His dental condition was good.

In early April 1957 during routine inspection, the works dental surgeon noticed an area of exposed bone in 65 region (765 were not present in the mouth). The patient was unaware of any lesion. He was removed from exposure.

The radiograph showed a small area of rarefaction. During the following few weeks he had a purulent discharge and some pain; there was no lasting response to

antibiotic therapy (penicillin and terramycin). In June 1957 he was referred to the consultant oral surgeon at hospital, and the radiograph then showed a larger area of rarefaction. A loose sequestrum was removed with a dental probe. During July 1957, 8 4] were extracted and 765] area curetted; it healed slowly without incident. In March 1958 the patient complained of pain in 15 area, and the radiograph showed a retained root. The root

was extracted under systemic antibiotics. The area did not heal in spite of frequent use of antibiotics and local treatment. In June 1958 he was referred back to the consultant with an area of exposed bone  $\frac{3}{8}$  in. diameter, but with no discharge; the radiograph showed small sequestra and these separated out without surgical intervention. The area healed with no further trouble. This case is interesting in view of the very short exposure to phosphorus (10 months). Case 9 had a similar total exposure.

**Case 6.**—A male, aged 32, was employed on phosphorus from May 1954. In May 1955 he was removed from exposure and 876 3] were extracted under general anaesthesia. The following week 21] and 1234 were extracted. Within the next 10 days all teeth were cleared from the lower jaws. He failed to heal, and he was seen at hospital in December 1955 complaining of pain and swelling in 65] region, teeth having been removed from this area some seven months previously.

Investigation showed a small spicule of bone lying superficially in 6] region, but the radiograph (Fig. 9) appeared within normal limits. He was given one mega-unit of crystalline penicillin daily, but his general condition deteriorated and a month after first being seen he was admitted to hospital. He had some swelling and pyrexia and temperature of 100°F. (37.7°C.), and was obviously toxic. The radiograph was still negative at this time.

Whilst in hospital he was given 250 mg. of tetracycline every six hours for eight days, together with local heat for the swelling. He rapidly improved and was discharged after 14 days. A radiograph taken shortly afterwards (Fig. 10) showed a well-defined sequestrum about  $2 \times 1.5$  cm. in 6] region. The sequestrum came away spontaneously three months later and subsequent healing of the mouth was uneventful. Fig. 11 is the radiograph of the jaw after the sequestrum exfoliated and

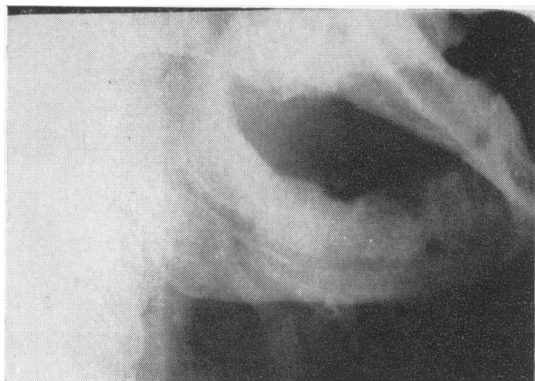


FIG. 9.—Case 6: Early radiograph before sequestrum demarcated.

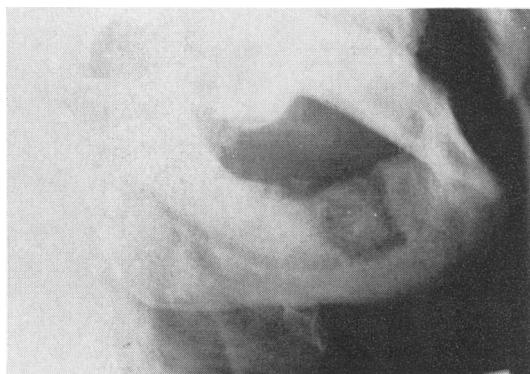


FIG. 10.—Case 6: Sequestrum becoming demarcated.

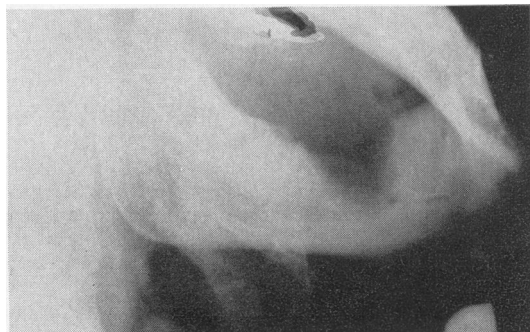


FIG. 11.—Case 6: Appearance after exfoliation of sequestrum.

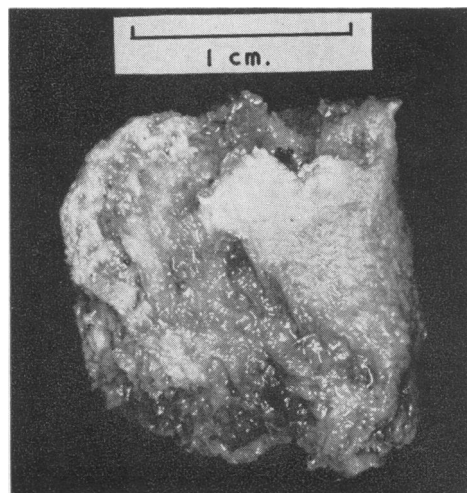


FIG. 12.—Case 6: The sequestrum.

Fig. 12 shows the sequestrum itself. A radiograph taken six years later (Fig. 19) shows considerable bone regeneration.

**Case 7.**—A male, aged 40, was employed on phosphorus plant from December 1946. He had an excellent mouth. In May 1948  $\overline{7}$  was filled but this tooth was extracted in June of that year. From then he required no further treatment except scaling until June 1953 when  $\overline{7}$  was filled and this was extracted in November 1953. He remained well until July 1957 when the root of  $\overline{7}$  was extracted. In August 1958 he developed an abscess in this region.  $\overline{568}$  were extracted. Seven weeks after these extractions he was well for one week and then had pain and swelling. Six weeks later, in September 1958, he was admitted to hospital with pain and a plum-sized swelling below the left angle of the jaw which was under considerable tension; he had anaesthesia of the left lower lip, a very toxic appearance, and the radiograph showed a large sequestrum forming in the left lower jaw.

The abscess was drained externally on admission. He made a good immediate recovery and was discharged a week later. He was readmitted in November 1958 for sequestrectomy. Under general anaesthesia the mucous membrane was reflected over the left lower jaw and a sequestrum enucleated. The cavity was packed with ribbon gauze in Whitehead's varnish. He made a good recovery and was discharged from hospital eight days later. He was followed-up as an out-patient and by June 1959 the sensation had returned almost fully to the left lower lip and the mouth condition was extremely good. The depression had almost completely filled with new bone.

**Case 8.**—A male, aged 32, was exposed to phosphorus from May 1955. He had  $\overline{7}$  extracted in October of that year after being removed from exposure.  $\overline{764}$  were extracted a week later and  $\overline{47}$  a week after that. He was well until November 1956 when he complained of pain in  $\overline{6}$  area; bone was seen to be exposed and it failed to heal.

In February 1957 he was seen at hospital complaining of the sore spot in the right upper jaw which had developed in November 1956.

On examination an area of bare sequestering bone was visible in  $\overline{6}$  region (Fig. 13) but radiographic appearances were negative. Later in February a further small sequestrum was also visible in  $\overline{76}$  region; both were small, and the patient removed them himself at the end of June 1957. Subsequent healing was uneventful.

**Case 9.**—A male, aged 32, started work in April 1955 and in November had 19 extractions. In January 1956 he complained of pain in  $\overline{76}$  area.

He was seen at hospital at the end of January 1956 complaining of pain and swelling in  $\overline{6}$  region of eight days duration, this tooth having been extracted two months previously. At this time radiographic appearances were within normal limits (Fig. 14). At the time he was referred he was under streptomycin from his medical practitioner. A fortnight later the swelling had

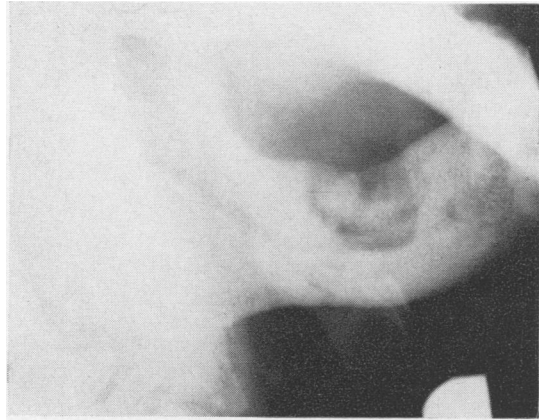


FIG. 14.—Case 9: Sequestrum not yet demarcated.

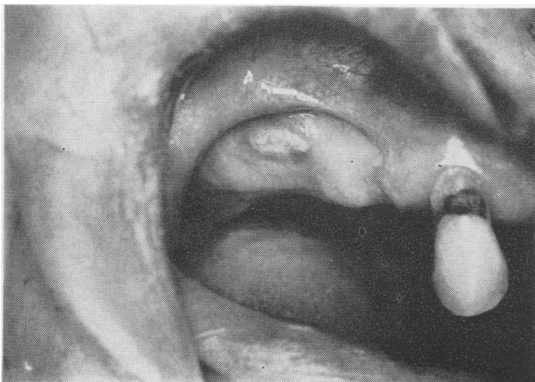


FIG. 13.—Case 8: Early intra-oral appearance of necrosis.

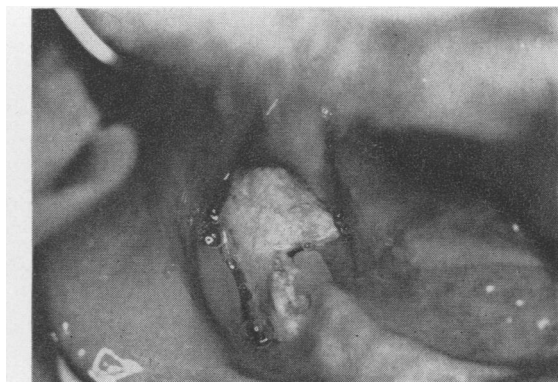


FIG. 15.—Case 9: Intra-oral appearance before exfoliation.



FIG. 16.—Case 9: Radiograph taken 21 days later shows sequestrum becoming defined.

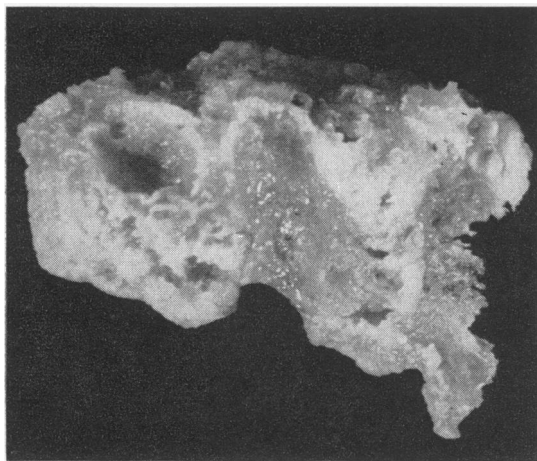


FIG. 17.—Case 9: Exfoliated sequestrum.

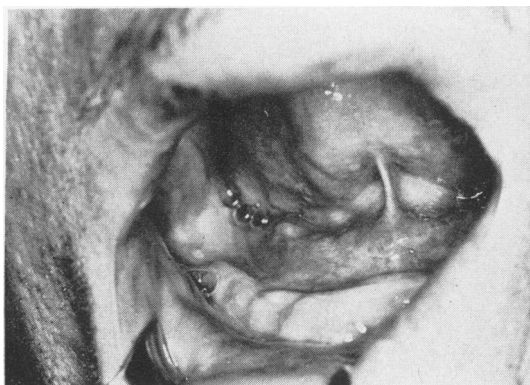


FIG. 18.—Case 9: Intra-oral appearance after healing, showing small depressions and healthy mucosa.

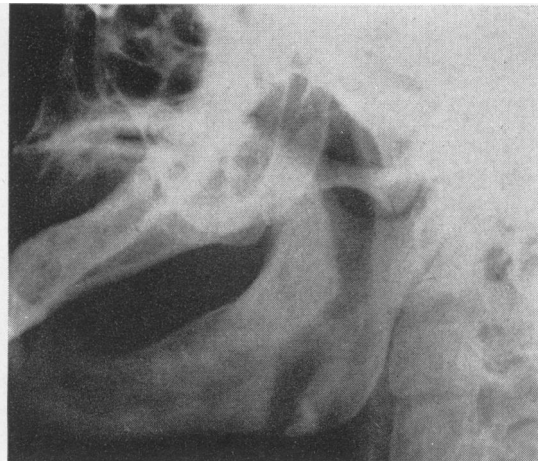


FIG. 19.—Case 6: Radiograph shows regeneration of bone following necrosis.

increased and pain was severe, but the radiograph was still negative. He was admitted a week later as he became worse. A course of tetracycline 250 mg. every six hours, heat, and kaolin poultice greatly improved his condition, and he was discharged 12 days later. The intra-oral appearance is shown in Fig. 15.

The radiograph showed a well-defined sequestrum in 61 region approximately  $2 \times 2$  cm. (Fig. 16). The sequestrum was shed spontaneously 13 months later in March 1957 and the exfoliated sequestrum is seen in Fig. 17. Subsequent healing was uneventful in this area but several very thin superficial sequestra developed in both upper and lower incisor regions; these gave no serious trouble.

Fig. 18 shows the completeness of the healing with only small depressions left covered by healthy mucosa.

This patient also developed necrosis within 10 months of first exposure (see Case 5).

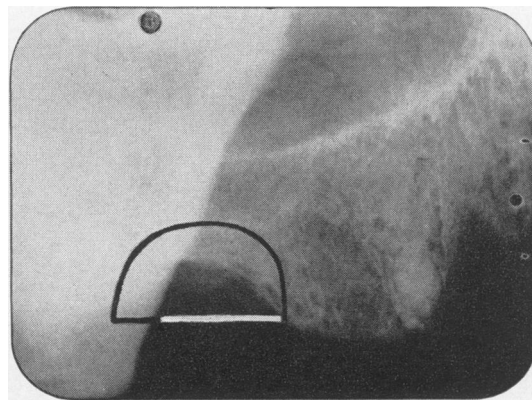


FIG. 20.—Case 3: Regeneration of the maxilla. Not as complete as in the mandible (cf. Fig. 19). Previous area of necrosis is marked.

**Case 10.**—A male, aged 34, was employed in phosphorus plant fitting shop from June 1946. He had minor dental treatment only from 1946 to 1954 when 7| was extracted. Healing was normal. In December 1955 he was declared unfit for exposure to phosphorus, and in January 1956 17 was extracted and healing was unduly delayed. He was declared fit for exposure again in February 1956. Progress was uneventful until October 1957 when a paradontal abscess was found in 14 area on routine examination. He was again given a "No Exposure" note, and 14 was extracted and oral penicillin was administered. The abscess resolved satisfactorily, healing within a week. In November 1957 pain occurred in 14 region, and the socket was curetted. The probe gave a rough sensation. In December 1957 a small sequestrum exfoliated and further small sequestra were removed in January, February, March, and September 1958, without any appreciable disability over this period.

Since then progress has been uneventful.

#### Cases of Delayed Healing and Residual Sepsis not Amounting to "Classical" Phossy Jaw

There are other conditions of the jaw, which are probably precursor signs, which do not develop to actual necrosis, and where there is little or no bone loss. Mention has already been made of the unhealthy appearance of the oral mucosa in phosphorus workers. In some men exposed, probably under 10%, extraction of teeth is followed by considerable delay in healing, without any sign of any other effect. Our dental records have not been kept in such a way that firm figures can be quoted although this finding has been frequently noted. Phosphorus workers are taken off exposure to phosphorus for extractions and not allowed back until they have clinically healed. The period of non-exposure is thus exactly known, but since non-phosphorus workers may not be re-examined, the rate of healing of their sockets has not necessarily been recorded. (This "clinical impression" is now the subject of a forward inquiry.)

**DH/1.**—Aged 30, exposed to elemental phosphorus for nine years. After extraction of four premolar and molar teeth from upper left quadrant, normal healing appeared to take place. Several months later, however, small sequestra started to work out accompanied by some local inflammation and a slight discharge; there was no pain, only slight discomfort. This condition continued for about 10 months; no surgical intervention or therapeutic treatment was carried out; eventually the area healed completely with no further sequestration.

**DH/2.**—Aged 36, exposed to phosphorus for one and a half years. After extraction of remaining anterior teeth, the canine areas refused to heal, having to be continually syringed and dressed for some eight weeks. Eventually the peripheral ring of bone around the canine

sockets sequestered without interference and sockets healed normally.

**DH/3.**—Aged 44, exposed to phosphorus for 23 years. After extraction of remaining anterior teeth the sockets took some nine weeks to heal in spite of constant local treatment and one course of systemic antibiotics. Small sequestra worked out during this period and final healing was normal in appearance though the alveolar ridge was rather irregular.

**DH/4.**—Aged 48, exposed to phosphorus for 17 years. After extraction of remaining 11 anterior teeth, the sockets were very slow to heal, bone resorption was slow and an alveolectomy was carried out, with systemic antibiotics. In spite of this, resorption of interdental bone was slow, and the patient had recurrent discomfort for over 18 months until the alveolus finally settled down.

**DH/5.**—Aged 41, exposed to phosphorus fumes for 16 years. There was "delayed healing" after isolated extractions until May 1958 when all remaining teeth were extracted in view of the deteriorating paradontal condition. Healing was slow, with small sinuses and bony splinters. Dentures were unsatisfactory due to the irregular alveolus; as two sinuses and one small area of exposed bone developed, alveolectomy was performed. He healed normally, but in December 1959 a few loose splinters developed in 11| region. The area was opened, bone removed, and he healed well.

**DH/6.**—Aged 42, he started in phosphorus in February 1955. Four months later, after removal from exposure, 6 and 6| were extracted, roots of 16 were left. 4, 15 and 4 were filled during the ensuing period, and the patient returned to phosphorus. Three months later a small spicule of bone was removed from 6| area and 15 months later a sinus developed in the same area. He was again removed from phosphorus and a small piece of bone was removed. 4 was causing pain and was extracted at this time. One month later 67| area was curetted, 5| root and 8| were extracted. Healing was delayed, but in May 1957 he returned to phosphorus as it was decided this was not true phossy jaw. Four months later 5 78 were extracted after removal from exposure, and in December of that year dead bone was removed from the area. Total clearance was undertaken in batches in February and April 1958. In May, pain and presence of bone were apparent in 34| area, and a small spicule worked out. Alveolectomy and stitching of flaps were undertaken. Full dentures were fitted a year after start of the clearance. Further pain and a small sequestrum occurred in 67 area, but this settled and he has had no further trouble.

Another not uncommon occurrence is failure of the alveolar bone to resorb after extractions, necessitating in some cases, cutting down on the bone and smoothing it. Whilst this condition also occurs in outside practice it appears to occur with



greater frequency in phosphorus workers. Phosphorus appears to have an adverse effect on all naturally occurring dental conditions, except caries.

The apparently contradictory effects of phosphorus causing osteoporosis in the formation of sequestra in the jaw, and a densifying effect on the alveolar margin in failure of bone to absorb is explicable. Sollmann (1957) writes that phossy jaw is due to a lowered resistance to infection and the effect of phosphorus on the blood vessels in the Haversian canals. He quotes Kassowitz as saying that small doses of phosphorus given to adult animals results in the Haversian and marrow canals being filled with dense bone of normal composition and structure. The densifying effect is probably due to delayed reabsorption of bone tissue from scanty formation of blood vessels.

Adams and Sarnat (1940) discuss the effect of oral doses of phosphorus in growing animals. Heimann (1946) has reviewed the literature on all aspects of chronic phosphorus poisoning and has given 57 references. There has often been disagreement between workers in this field.

#### The Biochemistry of Blood and Urine

It was decided to investigate 48 healthy men working on the phosphorus plant with a matched healthy control group not exposed to phosphorus, but only 28 of the controls would volunteer as the procedure involved blood letting, so that the matching for age and race was far from perfect. Exposure varied between one and 17 years in the phosphorus group.

The investigations consisted of haemoglobin estimations and total and differential leucocyte counts in all the men. The results are shown in Table 1 as the arithmetic mean for each group. There are no statistically significant differences

between the two groups, although two men with high lymphocyte counts were examined more closely; no reason was found for the increase. The finding is of interest as other workers have found in acute phosphorus poisoning that the only relatively constant finding is lymphocytosis. However, our finding is likely to be a coincidence; the men have continued to remain healthy over the past three years.

The first 10 men, five from each group, had determinations made of inorganic phosphorus, alkaline phosphorus, calcium, and magnesium in their plasma. The results are given in Table 2 and show no differences between the groups.

Other workers have reported high urinary creatinine in sufferers from phosphorus necrosis. The same two groups of five men each were investigated and the mean estimation in both groups was 141 mg./100 ml. The results varied widely (the weather was hot when specimens were taken).

In all 76 men radiographs of both hands at constant exposure were taken together with standard bone and ivory discs. The phosphorus group showed neither greater nor lesser density than the control.

One case of established necrosis (Case 3) was admitted to hospital for more extensive investigations.

**Case 3.**—Born October 28, 1921. Admitted to hospital March 11, 1957, with no previous illnesses of any note. He had had 7] extracted from the site which later became a sequestrum. Previously a gardener, he had worked on a phosphorus plant for four years until he was diagnosed. Apart from his mouth (healed) no abnormalities were detected on physical examination. He appeared to be a very healthy man.

The following investigations were carried out:

**Blood Count.**—Hb 100% (by colorimetric determination

TABLE 1  
HAEMATOLOGICAL STUDIES IN A GROUP OF 48 PHOSPHORUS WORKMEN COMPARED WITH 28 CONTROLS  
(MEAN FINDINGS)

Group	Hb (g./100 ml.)	Total Leucocytes per c.mm.	Polymorphs per c.mm.	Eosinophils per c.mm.	Monocytes per c.mm.	Lymphocytes per c.mm.
Phosphorus workers	16	8,190	4,870	201	375	2,740
Control	15.7	8,090	4,860	256	315	2,660

TABLE 2  
MEAN PLASMA DETERMINATIONS IN A GROUP OF FIVE PHOSPHORUS WORKERS AND FIVE CONTROLS

Group	Inorganic Phosphorus (mg./100 ml.)	Alkaline Phosphatase (units/100 ml.)	Calcium (mg./100 ml.)	Magnesium (mEq/l.)
Phosphorus workers	2.85	8.07	5.09	1.98
Control	2.9	8.4	5.08	2.01

of oxyhaemoglobin); M.C.V. and M.C.H.C. normal. White cell count 7,000/c.mm. with abnormal ratio; polymorphs were 30% (2,100/c.mm.), and lymphocytes 61% (4,270/c.mm.). Apart from this there was nothing remarkable in the blood film.

*Serum Chemistry.*—Normal in every respect tested, including blood urea, electrolytes, calcium, and phosphorus.

Results were as follows: Sodium 146 mEq/l.; potassium 4.7 mEq/l.; bicarbonate 19 mEq/l.; chloride 108 mEq/l.; inorganic phosphorus 3.5 mg./100 ml.; calcium 9.5 mg./100 ml.; magnesium 1.55 mEq/l.; creatinine 0.9 mg./100 ml.; serum albumin 4.2 g./100 ml.; serum globulin 3.2 g./100 ml.

Paper electrophoresis: Globulin slightly raised.

*Liver Function Tests.*—Plasma bilirubin: less than 1 mg./100 ml.; serum alkaline phosphatase, 7 units/100 ml.; serum acid phosphatase, 2 units/100 ml.; liver function flocculation tests normal. Serum cholesterol, 213 mg./100 ml.

Wassermann and Kahn tests negative.

Urinary amino-acid chromatogram normal.

*Urine.*—No albumin or sugar.

*Fractional Test Meal.*—Rather high acid but otherwise normal.

17-ketosteroid excretion: 8 and 12 mg./24 hours.

17-hydroxysteroid excretion: 19 and 21 mg./24 hours.

Faecal fat normal, 3 g. per day.

Repeat white cell count 9,500/c.mm.; polymorphs 50%, lymphocytes 44%.

*Calcium Metabolism Studies.*—Calcium balance was slightly negative, as was the nitrogen balance, such as might be expected in an active healthy man who is put substantially at rest. Phosphorus balance was neutral, and the division between urinary and faecal phosphorus was approximately normal, that is to say one-quarter to one-third of the daily output was in the faeces.

Calcium infusion study was carried out by giving calcium gluconate intravenously; 35% of the injected dose was excreted in 12 hours, and the skeletal retention during infusion was 42%. These figures are within the normal range.

Further examination of the plasma proteins was carried out by Dr. Soothill using immunological techniques, and it was found that though the gamma globulin was slightly raised, the immunological pattern of the protein was normal.

*Radiological Examination.*—Chest normal. Jaw—separation of the sequestrum was confirmed. Other parts of the bony skeleton revealed no evident abnormality.

Under prophylactic tetracycline and local anaesthesia a bone biopsy from the left iliac crest was carried out in the operating theatre. The specimen of cortical and cancellous bone appeared to be of normal consistency. The wound was closed with penicillin powder and linen thread.

Twenty days later the skin had not healed and an area 1 cm.<sup>2</sup> remained unepithelialized. There was some granulation tissue in the base and very little discharge. There was no pain. The lesion later healed normally.

## Discussion

**Time of Onset of Necrosis after First Exposure to Phosphorus.**—Oliver (1902) stated that the average time of onset after first exposure was five years, but to establish the date of the "onset" itself is usually difficult. For example in Case 7, did the onset occur when he first had pain in one tooth in an otherwise excellent mouth? The filling did not afford relief and the tooth had to be extracted. It was in the area of this tooth (the only area where there was an extraction) that the necrosis ultimately occurred; but there was no evidence that the process was clinically irreversible at that time. We have taken, as *length* of exposure, the time from first exposure to the time when the condition was regarded as probably due to phosphorus, and cases were usually notified to the Chief Inspector at this time as "suspected". In only one case, obviously not included in our list, did we have to withdraw the notification. The shortest period of exposure to phosphorus fumes leading to necrosis was 10 months (two cases) and the longest was 18 years.

Again with the generally long onset, assessment of the degree of exposure is very difficult. Fume is more prevalent during some periods of working than others. The atmospheric content of toxic substances varies greatly from point to point, and some men work harder and so breathe more. Finally, no estimations of phosphorus in the atmosphere had been taken at this time.

## Diagnosis

(1) *Clinical.*—One of the cornerstones in the diagnosis of phossy jaw is its difference from other forms of osteomyelitis met with in outside clinical practice. The diagnosis, where a sequestrum forms in the bone, and releases itself much later, may be distinguishable in a number of factors from classical osteomyelitis, and from all conditions except ionizing radiation or arsenic necrosis; in the last two cases the previous exposure is known. The radiographic picture is also very different.

(2) *Radiographic Appearances.*—In acute staphylococcal osteomyelitis the radiographic picture changes rapidly and closely follows the clinical course. In phosphorus necrosis, however, the diagnosis is suspected and sometimes clinically obvious before radiological changes are discernible (as in Case 6, Fig. 9). Once changes start the disease can be watched with radiographs, but these have not up to the present led to early diagnosis and treatment, or, more important, to prevention. With closer study we believe we may be able to detect

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changes at least earlier than heretofore, but more work is required on this.

**Organisms.**—The organisms vary from case to case and are often the normal flora of the healthy mouth but with predominance of one or more over the others. The presence of usually mild pathogens suggests that the mechanism of phossy jaw is that of a lowered resistance to the normal flora of the mouth, with which a healthy mouth can deal. The delayed healing after extractions supports this view. As has previously been reported, there was no increase in incidence of infection nor delay in healing in any lesions elsewhere than in the mouth in phosphorus workers compared with controls, as judged by a retrospective survey of medical records over one year.

**Personal Susceptibility.**—Our experience in this field confirms the claims of previous workers that there is a personal susceptibility to this disease. As previously mentioned, Bristowe found only 59 cases (past and present) amongst 2,500 employees, and Simon reported "very probably not more than two or three cases of jaw disease are annually prevalent in England". Oliver (1902) and Hunter (1957) state that less than 5% of persons exposed acquire the disease. Sollmann (1957) puts the percentage lower still and states that only 2% or 3% of exposed workers develop necrosis. Despite the fact that phosphorus is now manufactured on a scale a hundred times greater than before, there are, indeed, not more than "two or three cases annually prevalent in England".

The finding of cases not amounting to necrosis, but unquestionably affected by phosphorus, in less than 10% of those exposed, tends to confirm the above observations.

**Phossy Jaw Sequestra.**—Sequestra from phossy jaw have been well described in the literature and a typical one is seen in Fig. 12. Sequestra from acute staphylococcal osteomyelitis are sharp, white spicules of bone, dense and well calcified. Sequestra from phossy jaw are light in weight, yellow to brown in colour and present a worm-eaten appearance likened to pumice stone. They are osteoporotic and usually decalcified.

The sequestra separate from the surrounding bone and the area of demarcation can be clearly seen in the radiographs (Fig. 10). Since no area of rarefaction can be seen in the centre of the sequestrum it suggests that the cutting off of the blood supply must occur equally and suddenly at the periphery; the subsequent progress is slow but remorseless and eventually the detachment is complete. Where the periosteum is intact, regeneration of bone occurs.

Bristowe had reported no bone regeneration in the upper jaw and always some regeneration in the lower jaw. Our own radiographic observations over a century later partially confirm this astute clinical observation, for regeneration of the maxilla in Case 3 is much less complete than in the mandible of Case 6.

### Prevention

The preventive dental programme has developed in this country since the eighteen-nineties and the setting up of regular dental inspections was largely inaugurated by Wellings (Lecturer in Charge, Department of Histopathology, University of Birmingham, during the first World War) and Baron (1944) who developed the practice of never allowing a man who had had a jaw necrosis to return to further exposure to phosphorus.

The essence of our dental programme is to ensure maximal dental fitness in prospective employees. This has meant the rejection of otherwise suitable men in a time of great labour shortage. Before any exposure the workman is made dentally fit, and if this is impracticable he is rejected outright. A further reason for rejecting men with neglected mouths is that they are more than usually "accident prone".

After attaining adequate standards of dental fitness men are allowed to be exposed. Those most heavily exposed (on the phosphorus plant itself) are inspected every two months, those regularly exposed every four months, and those with casual exposure, for example, the works manager and the medical adviser every six months. If dental work necessarily involves anything other than minor procedures (small fillings or scaling) the man is taken off exposure beforehand, and he is kept off until he has clinically healed.

Radiographs are of limited use in prevention. It is good dental practice to take routine films of jaws to exclude retained roots and cysts, whether there is a toxic risk or not; but experience shows that necrosis can occur in the absence of any pathology visible on the radiograph. A far more important aspect of prevention is clinical observation and early attention to naturally occurring disease, and, if necessary, immediate removal from phosphorus exposure and early treatment for the disease should it occur. Once necrosis occurs radiographs are of value in following the course of the disease, but in the present state of our knowledge clinical observation is vastly more important in this connexion. Disease often follows surgical intervention, and good record keeping, itself a *sine qua non*, is most important in the assessment of the early doubtful case.

Despite these precautions, mild cases still occur. Kennon and Hallam (1944) referred in their paper to the "Era of Small Sequestra". We are glad that our reported cases were those of mild disease (compared with the past), with small sequestra and little or no resulting disability except the inevitable loss of natural teeth in the areas involved.

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good paper, it would have been merely the shadow of one without his help.

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